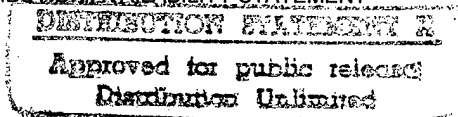


REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE Nov 97		3. REPORT TYPE AND DATES COVERED Final - 1 Mar 93-28 Feb 96	
4. TITLE AND SUBTITLE ONR Final Technical Report Circulation within Monterey Submarine Canyon				5. FUNDING NUMBERS G- ONR N00014-93-1-0403	
6. AUTHORS Dr. Leslie Rosenfeld					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Monterey Bay Aquarium Research Institute P.O. Box 628 Moss Landing, CA 95039				8. PERFORMING ORGANIZATION REPORT NUMBER NONE	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Department of the Navy Office of Naval Research 800 North Quincy Street Arlington, Virginia 22217-5000				10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES					
12a. DISTRIBUTION/AVAILABILITY STATEMENT 				12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) This project studied the circulation and transport of material in Monterey Submarine Canyon. It was carried out with Drs. Noble (USGS), Pilskaln (Univ. of Maine) and Schwing (PFEG/NMFS). Five subsurface moorings supporting twelve current meters with temperature sensors (six also measured conductivity and light transmission) and six sediment traps were deployed from August 1993 through August 1994. These data are presented in a USGS report. Numerous CTD casts were made during four cruises between August 1993 and November 1994. As expected, tidal frequencies dominated the energy spectra, and mean currents were very weak. Surprisingly, a three-day oscillation was found at all the measurement sites within the canyon. Two sediment traps deployed in the narrower region of the canyon recorded dramatically different flux regimes, with the 780 m trap collecting $2-4 \text{ g m}^{-2} \text{ d}^{-1}$, and the 1360 m trap collecting $22-60 \text{ g m}^{-2} \text{ d}^{-1}$. The predominantly lithogenic composition of the material in the deeper trap is evidence that canyon wall resuspension events dominate the flux regime there, whereas the lower concentrations of lithogenic material in the shallower trap, together with the seasonal pattern in the opal flux, indicate the influence of seasonal phytoplankton blooms. The mass fluxes measured in the wider part of the canyon were only $0.2-1.7 \text{ g m}^{-2} \text{ d}^{-1}$.					
14. SUBJECT TERMS Circulation, Submarine, Monterey Canyon				15. NUMBER OF PAGES 6	
				16. PRICE CODE	
SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT		

19971124 017

NSN 7540-01-280-5500

Computer Generated

STANDARD FORM 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

INFO QUALITY ASSURED &

ONR Final Technical Report
Circulation within Monterey Submarine Canyon
ONR Grant N00014-93-1-0403
P.I.: Leslie K. Rosenfeld
MBARI*
PO Box 628
Moss Landing CA 95039

*Leslie Rosenfeld is currently an adjunct scientist at MBARI, and a research professor at the NPS. Correspondance for her should be sent to: Code OC/Ro, Naval Postgraduate School, 833 Dyer Rd, Monterey, CA 93940; tel. (408) 656-3253; e-mail: rosenfel@oc.nps.navy.mil.

PROJECT SUMMARY

This project studied the circulation and transport of material in Monterey Submarine Canyon. It was carried out with Drs. Noble (USGS), Pilskaln (Univ. of Maine) and Schwing (PFEG/NMFS). Five subsurface moorings supporting twelve current meters with temperature sensors (six also measured conductivity and light transmission) and six sediment traps were deployed from August 1993 through August 1994. These data are presented in a USGS report. Numerous CTD casts were made during four cruises between August 1993 and November 1994. As expected, tidal frequencies dominated the energy spectra, and mean currents were very weak. Surprisingly, a three-day oscillation was found at all the measurement sites within the canyon. Two sediment traps deployed in the narrower region of the canyon recorded dramatically different flux regimes, with the 780 m trap collecting $2-4 \text{ g m}^{-2} \text{ d}^{-1}$, and the 1360 m trap collecting $22-60 \text{ g m}^{-2} \text{ d}^{-1}$. The predominantly lithogenic composition of the material in the deeper trap is evidence that canyon wall resuspension events dominate the flux regime there, whereas the lower concentrations of lithogenic material in the shallower trap, together with the seasonal pattern in the opal flux, indicate the influence of seasonal phytoplankton blooms. The mass fluxes measured in the wider part of the canyon were only $0.2-1.7 \text{ g m}^{-2} \text{ d}^{-1}$.

GOALS

Our long-term research objectives focus on the complex interactions among circulation patterns above, within, and past the mouths of submarine canyons, and with the complex topography associated with them. Our goal is to gain a dynamical understanding of how the circulation patterns within canyons are related to the topographic characteristics of individual canyons, and how features in those patterns can be generalized to fit a variety of similar canyons, so that simplified models of canyon circulation can be developed and evaluated. We would also like to quantify the role of currents within submarine canyons in eroding canyon walls, modifying the sediment patterns on canyon floors, transporting materials between the continental shelf and the deep-sea, and providing food for the large stocks of demersal fish that reside along canyon walls.

OBJECTIVES

Our objective is to use the CTD, sediment trap, and current meter and associated data that we collected during 1993-1994, to characterize the water circulation and vertical and lateral transport of suspended particle matter within the Monterey Submarine Canyon. We will estimate the transport of water and particulates through the Monterey Submarine Canyon; compare the low frequency circulation and density structure at a "wide" and at a "narrow" portion of the canyon; relate the circulation in the canyon to parameters of the flow over the canyon, deep flow outside the canyon, and to the topographic features of the canyon; evaluate the kinetic energy distribution, including tidal and higher frequencies, as a function of along-canyon distance (and hence canyon width) and depth; investigate the spatial patterns of particulate matter in the water column and examine the relationship between measured currents and volume transport of suspended particulate matter. We will compare our results to published theoretical predictions of circulation within canyons, and to numerical model results which are being generated as part of a related project.

APPROACH

We deployed a moored array and made CTD surveys from ships. These moorings supported 6 sediment traps and 12 current meters, 6 of which were modified to measure conductivity and light transmission, in addition to the standard current velocity and temperature. There was also a pressure sensor on each mooring. The array consisted of two cross-canyon sections. Three moorings are deployed across a wide section of the canyon, where the ratio of the internal Rossby radius to the canyon width is nearly unity. The bottom slope along the axis at this location is 0.8 degrees, which means that internal waves with period less than about 17 hours can freely propagate up-canyon past this point. Two moorings were deployed in a narrow section of the canyon, closer to the head, where the ratio of the internal Rossby radius to the canyon width equals 4. The along-canyon bottom slope in this region is about 3.5 degrees, very close to the expected slope of the characteristics for internal waves of semi-diurnal period.

Flow above the canyon over the narrow section was monitored with a downward-looking acoustic Doppler current profiler on a surface mooring supported by MBARI. At the wide site, there was one current meter above the canyon sill on the central mooring. Near-bottom flow and suspended sediments within the canyon, but 32 km further down-canyon in water depth of 3223 m, was monitored by a mooring deployed by the USGS. Researchers from the Naval Postgraduate School measured flow over the continental slope south of the canyon. In addition, as part of his Ph.D. work, LCDR Petruncio (for whom Rosenfeld served as co-advisor) analyzed data from two NPS cruises designed to look specifically at the internal tide in the canyon, and applied the Princeton Ocean Model to the study of the generation and propagation of internal tides in idealized submarine canyons.

ACCOMPLISHMENTS

We deployed 6 subsurface moorings (5 funded by ONR and an additional one funded by USGS) in Monterey Canyon in August 1993, and successfully recovered them all in

August 1994. Nearly all instruments worked as planned. These data have all been processed and are presented in a USGS open file report. All of the mass flux and geochemical analyses on five of the six sediment traps have been completed. (One trap was washed out during recovery of the moorings). During the mooring deployment and recovery cruises, as well as on NMFS cruises in June and November 1994, multiple CTD casts were made to determine the density and light transmission fields in the vicinity of the moorings. All of these data have been processed. In addition, ancillary data from local wind and sea level records has been collected, processed, and merged into the Monterey Canyon data base. In a related project, CTD and VM-ADCP data collected repeatedly along a section of the canyon axis over 25 hour periods during April and October 1994 have been processed and analyzed. The results from these data, as well as comparisons with simulations from a primitive equation numerical model, form the basis of Petruncio's Ph.D. dissertation (1996).

RESULTS

The energy in the currents in Monterey Canyon is predominantly tidal, with the largest tidal amplitudes occurring toward the floor and the head of the canyon. A weak mean flow at the narrow site was upcanyon near the canyon rim and downcanyon deeper in the canyon. There was no discernible mean flow at sites in the wider portion of the canyon. A 3-day oscillation was commonly found at most measurement sites in the canyon and not found at the measurement site outside of and above the canyon axis. The oscillation was coherent across the canyon, between the narrow and wide-axis sites, and between these sites and deeper USGS site, thus indicating its large spatial scale. There was no perceptible phase lag in the 3-day oscillation among these sites, with the exception of the shallowest instrument on the north side of the canyon at the inner array which was 180 degrees out of phase with the other sites.

The two sediment traps deployed in the narrow head region of the canyon recorded dramatically different sediment flux regimes, with the upper 780 m trap collecting 2-4 g m⁻² d⁻¹ over the 12-month deployment period, and the deeper 1360 m trap providing extremely high flux values that ranged from 22-60 g m⁻² d⁻¹. The geochemical composition of the material collected in the 1360 m trap is predominantly lithogenic (60% by dry weight), supporting the inference that canyon wall resuspension events dominate the sediment flux regime at this particular locality and are primarily responsible for the large mass fluxes of sedimentary material. In contrast, the 780 m trap contained significantly lower concentrations of lithogenic material (42%) and a relatively higher concentration of opaline silica (34%) as compared to the deeper trap (27% opal). This, coupled with the seasonal pattern observed in the opal flux with moderately high fluxes in the fall, minimal values in the winter, and maximum fluxes in the spring, indicates that the particulate material delivered to this trap was influenced to at least a moderate degree by the seasonal phytoplankton blooms occurring in the overlying surface waters.

The sediment flux data obtained from the traps deployed in the wide axis region of the canyon display a number of characteristics which differ significantly from the trap data collected further up-canyon. The traps in the wider part of the canyon measured

substantially lower sediment fluxes, only $0.2\text{--}1.7\text{ g m}^{-2}\text{ d}^{-1}$. All three of these traps displayed seasonal patterns in the total mass, opal, and organic carbon fluxes with moderately high values in the fall, minimal values during the winter, and maximal fluxes in the spring upwelling period. The influence of seasonal phytoplankton blooms on the delivery of particulate material to the traps in these locations is also reflected in the geochemical content of the collected material. The average opaline silica content of the particle matter collected in all three wide canyon axis traps was 56%, compared to a relatively low lithogenic content of 25%. Another significant difference between the narrow canyon axis and wide canyon axis traps was in the POC content of the trapped materials and their C:N ratios. Although the POC fluxes to the traps in the narrower part of the canyon were substantially higher (a function of the high total mass flux values), the average POC content of those traps (2.5%) was less than that obtained for the traps in the wider part of the canyon (5%). Additionally, the C:N ratios determined for the narrow canyon axis trap material were primarily 10 or greater, whereas the wide canyon axis trap sediments had lower values of 7 and 8. Lower C:N ratios (i.e., close to the Redfield ratio) are indicative of particulate material which is less degraded and contains a greater portion of labile organic compounds as compared to C:N ratios of 10, a value more typical of bottom sediments and/or recycled particulate organic matter.

The monthly lithogenic flux pattern determined from the three traps in the wider part of the canyon was highly variable between trap localities. Basically, the traps which were located near the canyon walls displayed a greater degree of monthly variability in the amount of lithogenic material they collected compared to the trap deployed in the central region of the canyon axis. The magnitude of the axis trap lithogenic fluxes, which had an average value of $80\text{ mg m}^{-2}\text{ d}^{-1}$ was also substantially less than that measured with the other two traps where lithogenic fluxes frequently exceeded $100\text{--}200\text{ mg m}^{-2}\text{ d}^{-1}$. The obvious conclusion from these data is that the traps deployed near the canyon walls are subject to periodic resuspension events of wall sediments, but these "events" do not appear to affect the trap deployed in the center of the canyon. This indicates that in this region of the canyon, sediment resuspension off the canyon walls is fairly localized and not of significant volume or magnitude to affect the central axis region.

Petruncio et al. (1997) found that the internal tide energy in Monterey Canyon is concentrated in a 150-200 m thick beam centered approximated 150 m above the canyon floor. In April 1994, there was strong evidence that the energy propagated upward along the canyon floor, whereas in October there appeared to be a standing wave. The application of the Princeton Ocean Model with an idealized canyon geometry was able to reproduce many aspects of the observed internal tide.

IMPACT FOR SCIENCE

According to Hickey (1995), roughly 20% of the shelf between Alaska and the equator is incised by submarine canyons. These areas are likely sites of enhanced mixing due to the large internal wave activity, and they may provide a relatively effective mechanism for transporting sediments, sewage sludge or other materials off the shelf. They are also, at least off California, a primary habitat for commercially valuable demersal fish stocks and

it has been suggested that submarine canyons have an important effect on the entire marine food chain (Hickey, 1995). Up to this point, there have been very few studies of the circulation and transport processes in large canyons, that can be used to assess the complex interactions between topography, circulation, and particle transport in these areas.

RELATIONSHIPS TO OTHER PROJECTS

Paduan and Rosenfeld, under ONR sponsorship, are extending the previously mentioned numerical modelling studies to include more realistic bathymetry. The data sets collected under the completed grant (N00014-93-1-0403) will be used for verification of those model results. The work completed under this grant has also contributed to Monterey Canyon being chosen as a field site for the ONR Littoral Internal Wave Initiative, under the auspices of which, together with NSF sponsorship, a field program was carried out in August 1997 focussing on the turbulence associated with the internal wave field in the canyon.

USGS has a continuing program in Monterey Bay, with the goal of generating a sediment budget for the Monterey Bay National Marine Sanctuary. As part of this program, they continue to maintain a mooring on the outer canyon axis.

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STATISTICAL INFORMATION

1 Publication:

Petruncio, E.T., L.K. Rosenfeld, and J.D. Paduan, 1997. Observations of the internal tide in Monterey Submarine Canyon, *Journal of Physical Oceanography*, accepted.

1 Graduate student

0 Patents

1 Technical Report:

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- 0 Committee or panel service
- 0 Honors and awards